

PIANC InCom - Work Group 29

Innovations in Navigation Lock

Design

Overview and Project Review Summary

Prof. Philippe Rigo
Chairman WG29

Peter Hunter

John Clarkson

WG29 Members

- **RIGO Philippe** (Chairman) Belgium
- **BÖDEFELD Jörg** - Germany
- **BOS Jan** - The Netherlands
- **CLARKSON John** - USA
- **DALY Fabrice** -France
- **FERNANDEZ Jose Luis** - Spain
- **HIJDRA Arjan** - Netherlands
- **HIVER Jean-Michel** - Belgium
- **HOLM Olli** - Finland
- **HUNTER Peter** - UK
- **MILLER Dale** - USA
- **PECHTOLD Erwin** - The Netherlands
- **PICHON Nicolas** - France
- **POLIGOT-PITSCH Stephanie** - France
- **SARGHIUTA Radu** - Romania
- **THORENZ Carsten** - Germany
- **TARPEY Michael** - USA
- **THOMAS Rik** - Belgium
- **WONG Juan** - Panama
- **WU Peng** - P. R. China

Meetings of the Working Group

- Brussels (Belgium, February 2006)
Lappeenranta (Finland, June 2006)
Magdeburg (Germany, November 2006)
- Grenoble (France, March 2007)
Amsterdam (Netherlands, Oct 2007)
- Brussels (Belgium, January 2008)
- Three Gorges (China, June 2008)
- Sevilla (Spain, Dec 2008)

INNOVATIVE CATEGORIES

Hydraulics

Operations and Maintenance

Environmental

Design

Construction

Miscellaneous

WG29 - Navigation Locks

Locks are key structures for the development of commercial and leisure navigation in rivers and canals.

Locks are also strategic infrastructure for port development.

In low-lying countries, locks have an important function in flood defence.

Innovation applies to the biggest...



... and the smallest



WG29 - Lock INNOVATIONS

The report:

- **complements the 1986 report.**
- **focuses on innovative techniques developed since that report**
- **covers all aspects of lock design**
- **does not duplicate material included in the 1986 report**
- **targets innovations and changes occurring since 1986**

WG29 - Lock INNOVATIONS

WG29 report has three major parts:

1. *An exhaustive list of **design goals** associated with locks. This section is important for decision makers who have to launch a new project.*
2. *Review of **design principles** that must be considered by designers. This section is methodology oriented.*
3. *Review of all major **technical aspects** (hydraulics, structures, foundations ...), focussing on changes and innovations occurring since 1986. This section is technically oriented.*

Perspectives and trends for the future are also considered.

When appropriate, recommendations are provided.

Finally there is a detailed collection of project reviews for many lock projects since 1984 (summarised in the report and in full on a CD).

WG29 - Lock INNOVATIONS

**Major changes since 1986 concern:
Maintenance and Operation
aspects,**

**Aspects to be included in criteria
as goals in the conceptual and
design stages of a lock.**

**Renovation and rehabilitation of
existing locks are also key issues
for the future.**

DESIGN PRINCIPLES

- **“Risk based design” versus “Deterministic approach”**
- **“Life cycle cost optimisation” versus “Least construction cost”**
- **Use “Early Design Tools” for preliminary design stages**
- **Use of “Numerical Modelling” as design tool**

LAYOUT OF HYDRAULIC SYSTEM

The hydraulic systems for filling and emptying locks can be divided into two main types. One is filling and emptying “through the heads”; and the other is the “through longitudinal culverts”.

With the “longitudinal culvert” system there are several types of typical layouts:

- Wall culvert side port system*
- Wall culvert bottom lateral system*
- In-Chamber longitudinal culvert system (ILCS)*
- Longitudinal culverts under the lock floor*
- Dynamically balanced lock filling system*
- Pressure chamber: Instead of culverts, a large chamber is built under the floor for the full width and length of the lock with a series of holes in the floor to fill the lock*

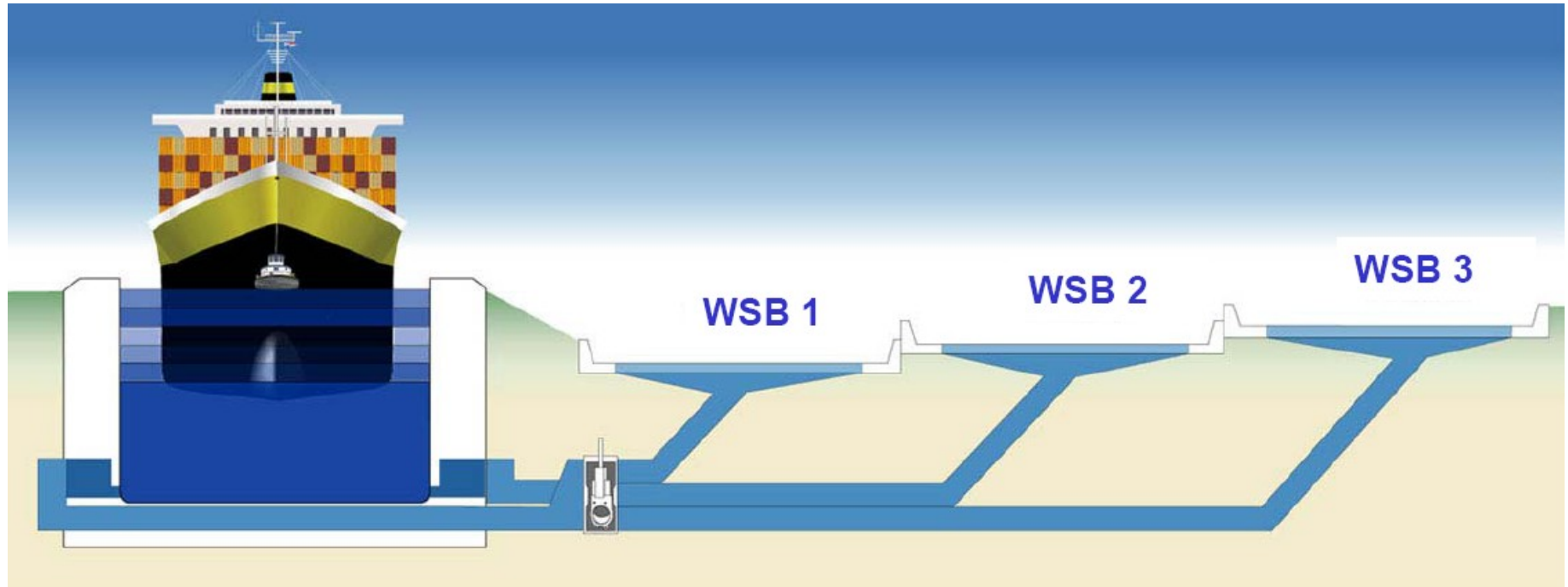
Water saving basins

There are two kinds of water saving basins:

- **First, the standard concept with separated WSBs (located on one side or both sides of the lock, on a series of steps)**
- **The integrated system which integrates the WSBs in the two side walls, which make the lock structure more stiff, compact and less land consuming.**

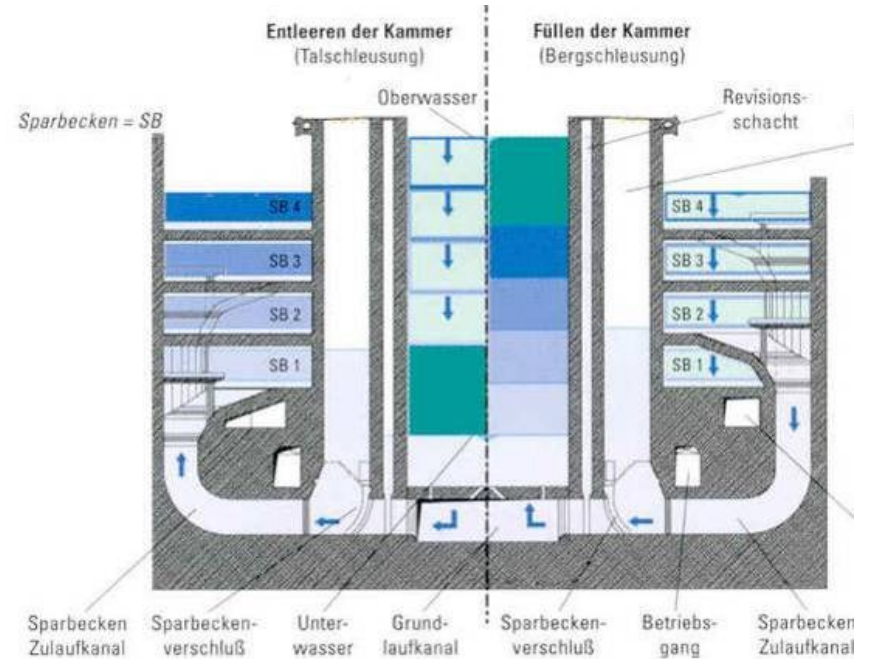
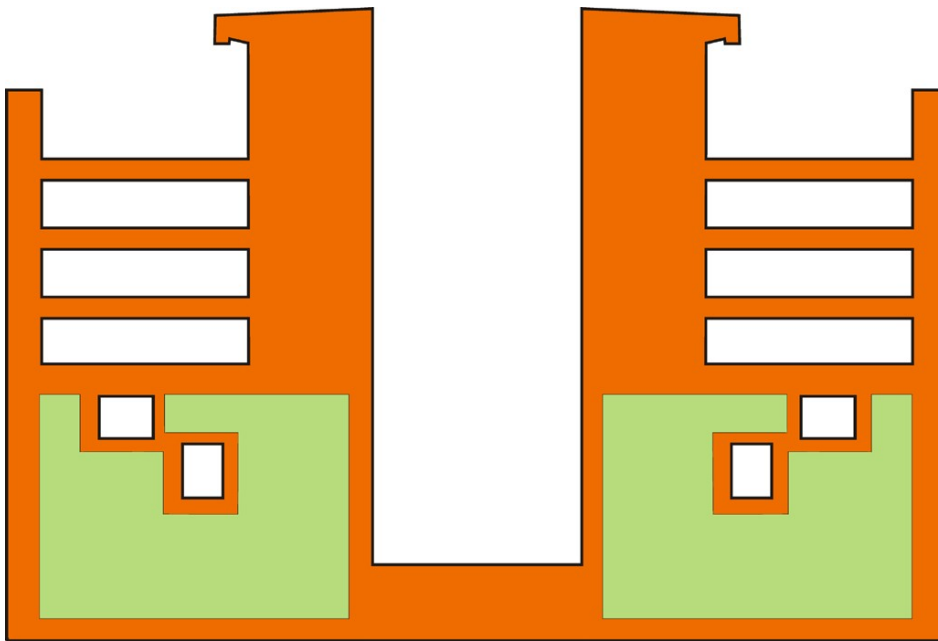
Fig. 4.3 : Cross-sections in lock sidewalls with integrated WSBs

Water Saving Basins (WSBs)

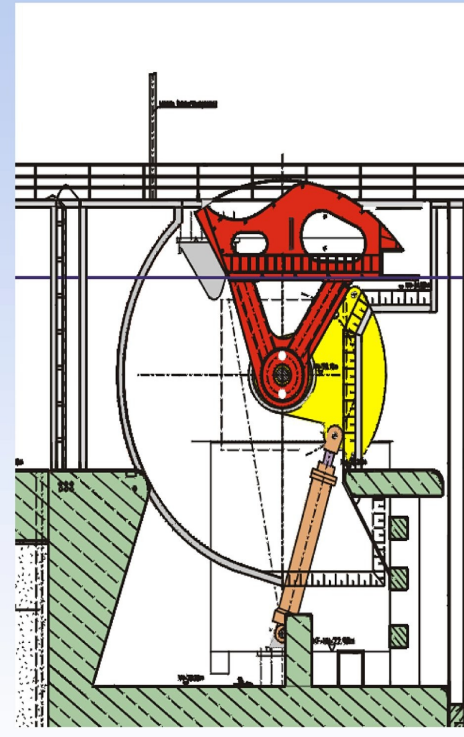
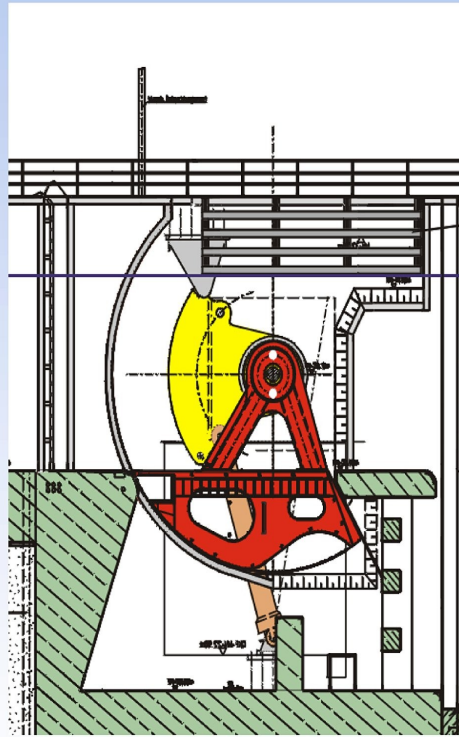
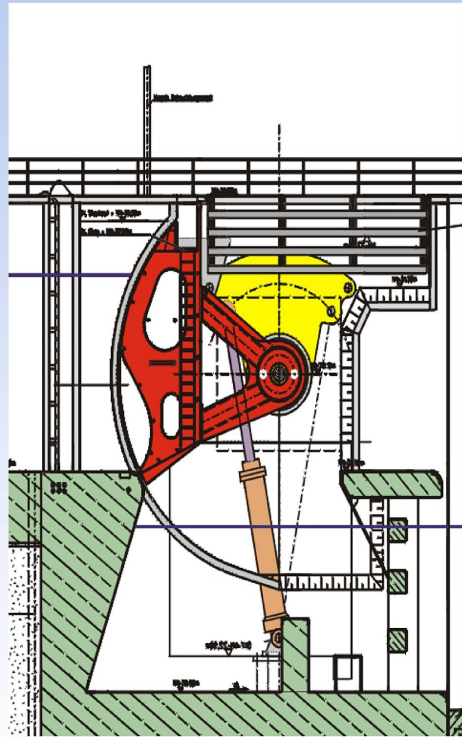


Integrated WSBs

Cross-sections in lock sidewalls with integrated WSBs



GATES AND VALVES





Rotary gate in raised position

Mechanical devices (actuators,...)



Innovative Summary Table

	Hydraulics			O & M			Environmental			Design/ Construction			Misc.		
This could be simplified by combining the Unproven and New Concepts into one category. This would have 3 categories.															
Project Reviews															
1-01A Kallo Sea					PT	PT				PT			UT	UT	
1-02A Monsin Lock Deepening	PT			PT		PT							PT		
2-01A Brazil Waterways	PT									PT					
3-01Gezhouba															
3-02 Grand Canal	PT									PT					PT
3-03 HonghuA															PT
3-04 J injitan	PT														PT
3-05 Mengli	PT				PT					PT					

PT
UT
NC
AC

¹ Proven Technology (PT) - The feature has been built and validated by time and experience

² Unproven Technology (UT) - The feature has been built but it has not yet been validated by time and experience.

³ New Concept (NC) - The feature is currently in the design process, but has not yet been built.

⁴ Advanced Concept (AC) - the feature is been evaluated and/or tested in the research stage.

Examples of Project Reviews

Hohenwarthe (6-03)

The double lock at Hohenwarthe:

- has a high static load because of its enormous permanent weight, because of the high and large-area embankment and the water load.
- During design, settlement calculations showed that a design with expansion joints creates settlement differences which cannot be handled with conventional waterstops
- Solution: to construct a monolithic bottom plate, 250 m long, 55m wide and 5.5 m high.

Areas of Innovation

Hydraulic	O & M	Envir on	Design / Constru ct	Mis c
-----------	-------	-------------	------------------------------	----------

Lock Dimensions

Length	190 m	Lift:	
Width:	12.5 m	Depth	



Caisson Method (7-01)

A unique construction method. The lock chamber is constructed on the ground surface. When complete the soil is removed beneath the lock chamber and it is lowered into its final position.



Areas of Innovation

Hydraulic	O & M	Environment	Design / Construct	Misc
-----------	-------	-------------	--------------------	------

Lock Dimensions

Length		Lift:	
Width:		Depth	

Lith (7-02)

A new lock chamber built to replace a small existing lock. The lock chamber is built on the ground surface and the ground beneath is then removed to lower the chamber to its final elevation.



Areas of Innovation

Hydraulic	O & M	Environment	Design / Construct	Misc
-----------	-------	-------------	--------------------	------

Lock Dimensions

Length	200 m	Lift:	4.7 m
Width:	18.5 m	Depth	

Seine-Nord Europe (5-07)

A new canal 106 km long with seven locks as standardized as possible. One lock will be (low lift), six locks from 15m to 30 m lift.

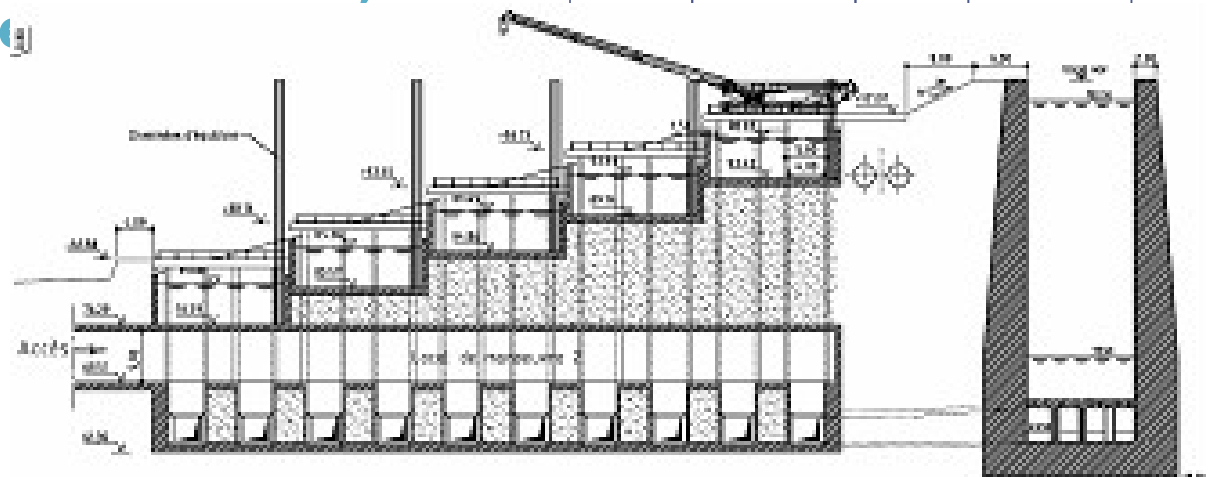
One of the main challenges is water resources management. That explains the use of water saving basins and pumping plants in the locks. Moreover, the canal will have watertight.

Areas of Innovation

Hydraulic	O & M	Environment	Design / Construct	Misc
------------------	------------------	--------------------	---------------------------	-------------

Lock Dimensions

Length	106 km	Lift:	15 - 30 m
Width:	12.5 m	Depth	



Naviduct Krabbersgat (7-03)

Areas of Innovation

The 'Naviduct' at 'Krabbersgat' at Enkhuizen is a combination of a double 42 M x 160 M navigation lock that includes an underpass for road traffic.

Hydraulic	O & M	Environment	Design / Construction	Misc
-----------	-------	-------------	-----------------------	------



Panama Canal Expansion (8-01)

The unique Panama Canal Third Locks Project:

- Three-step locks,
- Each with 3 water saving basins
- Side filling and emptying system
- Non-dimensional hawser force parameters for large ocean-going vessels
- fresh and salt water on the lock limits
- lock structures sitting on two different foundation conditions
- Seismic design
- 365/24/7 uninterrupted use

Lock Dimensions

Length	1281 m	Lift:	27m
Width:	55 m	Depth:	18.3 m

Areas of Innovation

Hydraulic	O & M	Environment	Design / Construction	Misc
-----------	-------	-------------	-----------------------	------



- Lock Dimensions
- Length:1,621.0 m Lift:113.0 m
- Width:34.0 m Depth:5.0 m
- Project Description
- The total design lift height of the Three Gorges lock is 113m. The maximum water head of intermediate chambers is 45.2m. The dynamically balanced system with four manifolds was chosen as filling and emptying system. Combined measures were taken to tackle the cavitation problem.



• Three Gorges Project

High Rise Navigation Lock

Innovation

High rise navigation locks are based on the intensive use of water saving basins which split the lift height to avoid cavitation and provide significant water saving (up to 90 %).

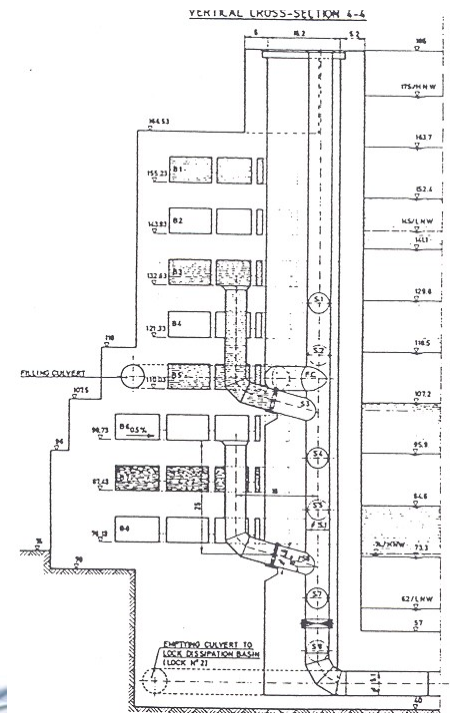
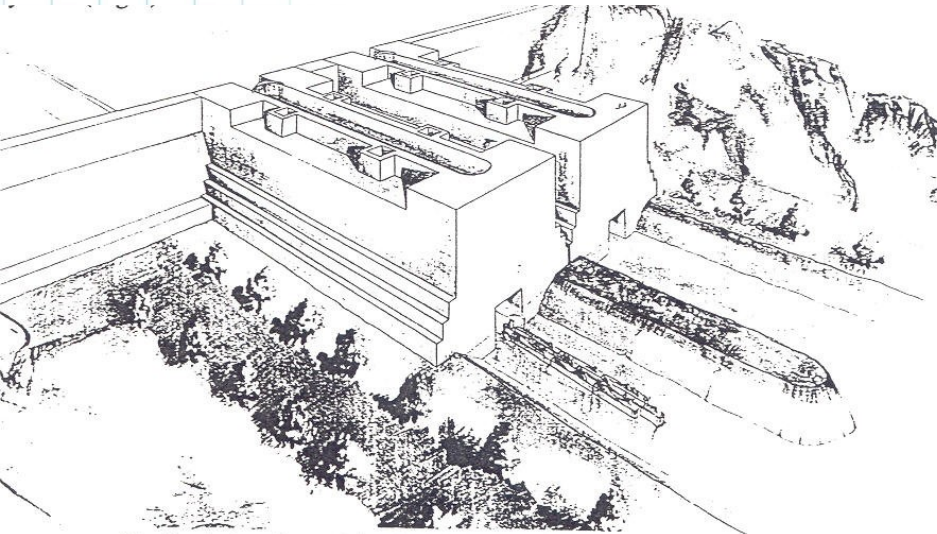
Lift height of 80m and even 113 m can be reached with a single lock.

Areas of Innovation (1.04)

Hydraulic	O & M	Environ	Design / Construct	Misc
-----------	-------	---------	--------------------	------

Lock Dimensions

Length:	> 200m	Lift:	40-120 m
Width:	25 to 60 m	Depth:	NA



Brazil Waterways (2-01)

A presentation of the state of inland navigation for Brazil and a discussion of the issues to be overcome to improve waterborne transportation in Brazil.

Areas of Innovation

Hydraulic	O & M	Environment	Design / Construct	Misc
-----------	-------	-------------	--------------------	------

Lock Dimensions

Length	N/A	Lift:	N/A
Width:	N/A	Depth	N/A



Juankoski Canal (4-01)

Locks built in rock.

Instead of building concrete lock walls anchored to the rock, a floating pontoon was designed inside the lock for the mooring of the boats and to protect the boats against collisions to the lock walls. With this design solution, the lock walls could be left with a rock surface, which led to significant cost savings.

Areas of Innovation

Hydraulic	O & M	Environment	Design / Construct	Misc
-----------	-------	-------------	--------------------	------

Lock Dimensions

Length	35 m	Lift:	6 - 6.5 m
Width:	8 m	Depth	2.4 m



Suspended Mitre Gate (7-05)

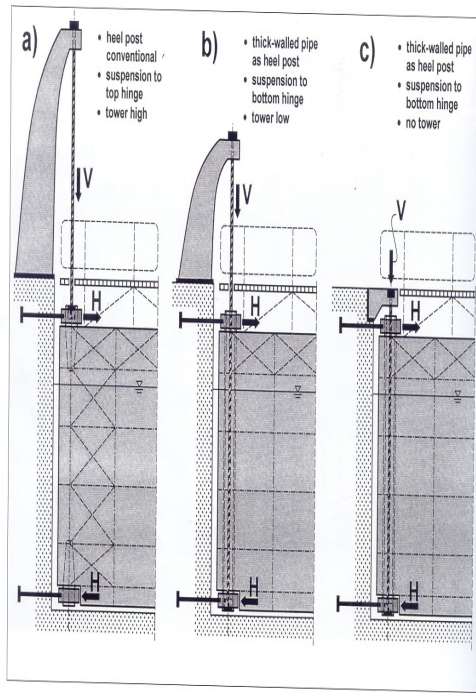
This paper outlines problems with mitre gate pintles and evaluates potential methods to mitigate the problem.

Areas of Innovation

Hydraulic	O & M	Environment	Design / Construct	Misc
-----------	-------	-------------	--------------------	------

Lock Dimensions

Length	N/A	Lift:	N/A
Width:	N/A	Depth	N/A



Keitele Canal (4-02)

Project Description

Lock gates are sector gates. The fall heights vary from 2.5 m to 7.8 m. The filling and emptying of locks is done with the gates. The gate drive system is electro-mechanical.

a. Lock Design Methodology:

The locks are designed for both timber floating and barge traffic. The design barge is Europe II-type push-barge. The design timber raft is 22 bundles long and 4 bundles wide (one bundle is approx. 5 x 2.5 m). The bundles are floated through the locks with a current created by opening upper or lower gate somewhat.

Areas of Innovation

Hydraulic	O & M	Environment	Design / Construct	Misc
-----------	-------	-------------	--------------------	------

Lock Dimensions

Length	115 m	Lift:	
Width:	16 m	Depth	4 m



Cardiff Bay (10-2)

The three new locks for the Yacht Basin use sector gates to fill the locks but take special care to reduce turbulence



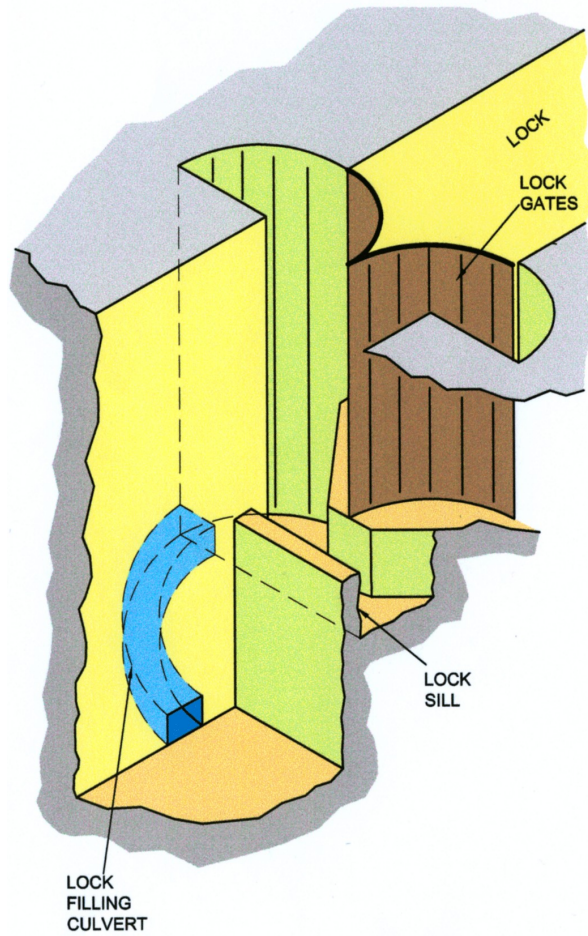
Areas of Innovation

Hydraulic	O & M	Environment	Design / Construct	Misc
-----------	-------	-------------	--------------------	------

Lock Dimensions

Length		Lift:	
Width:		Depth	

Cardiff Bay (10-2)



Cardiff Bay (10-2)



Reverse Head Mitre Gates (10-05)

Project Description

UK locks located in tidal zone used props on the "upstream" face of their mitre gates to resist reverse head.



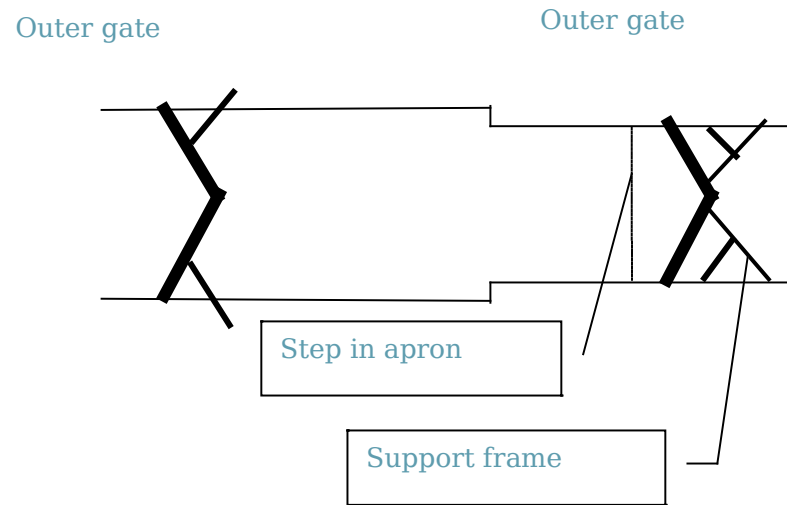
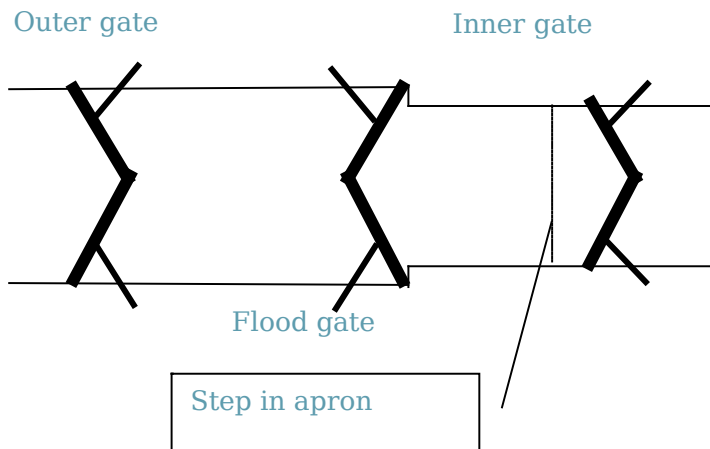
Areas of Innovation

Hydraulic	O & M	Environment	Design / Construct	Misc
-----------	-------	-------------	--------------------	------

Lock Dimensions

Length		Lift:	
Width:		Depth	

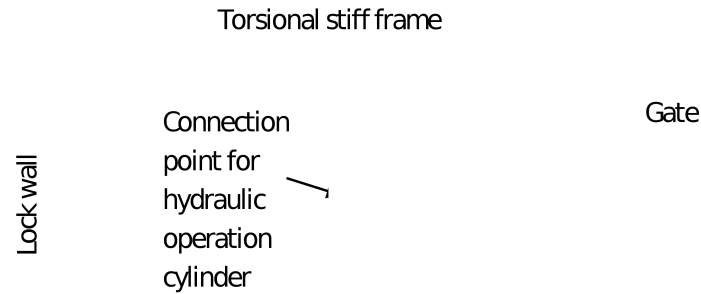
Reverse Head Mitre Gates (10-05)



Reverse Head Mitre Gates (10-05)



Plan View of gate and support frame



Diagrammatic cross section of lock

Golbey Gate Replacement (5-01)

Gate composed of a circular-shaped skin plate made of glass fibres reinforced polymer (GRP or CVR = composite verre-résine) stiffened by blocks of sandwiched CVR and foam. The sluice gates are stainless steel plates. The gate is hinged to the old masonry by adjusting stainless steel frame as U form supporting hinges.

Areas of Innovation

Hydraulic	O & M	Environment	Design / Construct	Misc
-----------	-------	-------------	--------------------	------

Lock Dimensions

Length		Lift:	
Width		Depth	



Self Propelled Floating Gate

(1.03)

Innovation

Alternative concept to the standard rolling gates (wheelbarrow, hydrolift) for large maritime locks.

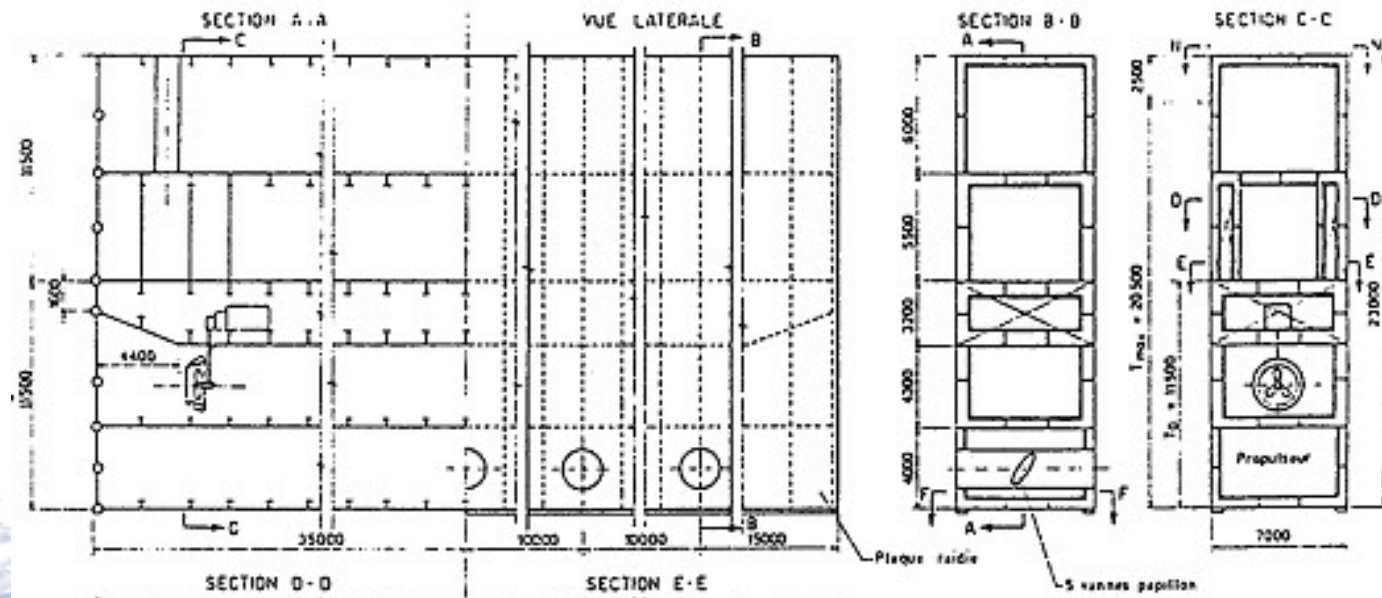
The idea is to use a floating gate that is self propelled to close/open the lock (as a transversally rolling gate does).

Areas of Innovation

Hydraulic	O & M	Environ	Design / Construct	Misc
-----------	-------	---------	--------------------	------

Lock Dimensions

Length:	NA	Lift:	2-10 m
Width:	20 to 100 m	Depth:	10-20 m



Composite Vertical Lift Gate (5-02)

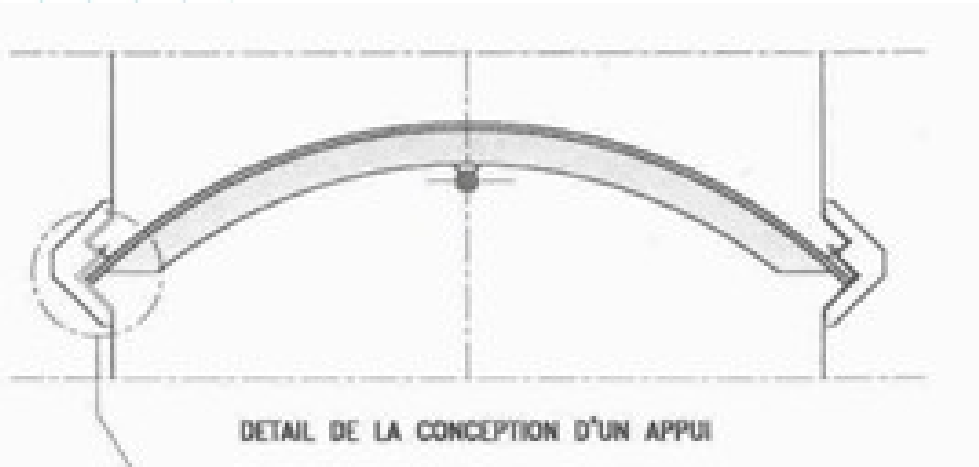
This is a research project in France to evaluate the potential use of composite (epoxy resin) materials for construction of a vertical lift gate.

Areas of Innovation

Hydraulic	O & M	Environment	Design / Construction	Misc
-----------	-------	-------------	-----------------------	------

Lock Dimensions

Length	N/A	Lift:	15 m
Width:	12 m	Depth	5 m



Lock Rhone CNR(5-03)

Arch Gate and impact protection system

Areas of Innovation

Hydraulic	O & M	Environment	Design / Construct	Misc
-----------	-------	-------------	--------------------	------

Lock Dimensions

Length		Lift:	
Width:		Depth	



PIANC WG 29

Bristol Gate Replacement (10-01)

This is a mitre gate replacement project that reduces maintenance.

Areas of Innovation

Hydraulic	O & M	Environment	Design / Construct	Misc
-----------	-------	-------------	--------------------	------

Lock Dimensions

Length	267 m	Lift:	
Width:	30.5 m	Depth	14.7 - 16.6 m



Dalmuir Drop Lock (10-03)

Project Description

The re-opening of the Forth and Clyde Canal crossing Scotland (approximately between Edinburgh and Glasgow) used various techniques to re-instate the canal where it was crossed by roads where the canal crosses the major A814 road in Clydebank, in Glasgow. This consists of a long lock chamber allowing the canal surface beneath the A814 road to be lowered to allow vessels to pass beneath that road.

Areas of Innovation

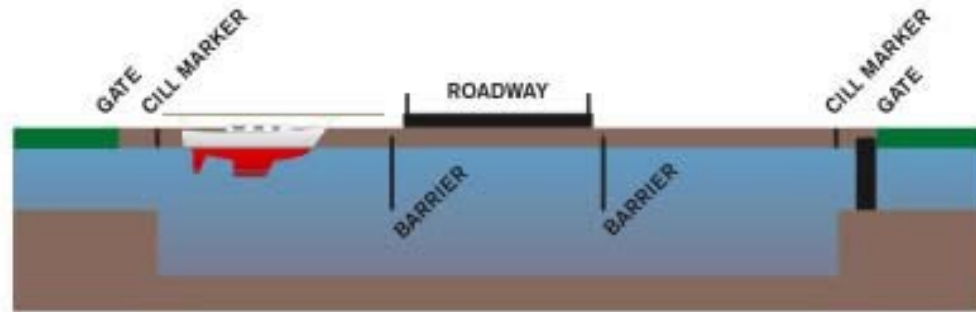
Hydraulic	O & M	Environment	Design / Construct	Misc
-----------	-------	-------------	--------------------	------

Lock Dimensions

Length		Lift:	
Width:		Depth:	



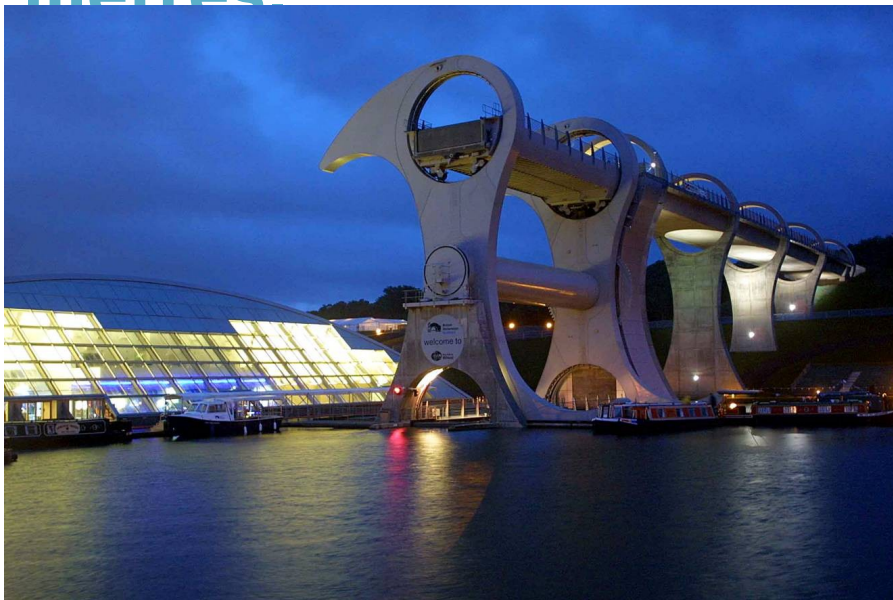
Dalmuir Drop Lock (10-03)



Falkirk Wheel (10-04)

Project Description

Two gondolas act as moving lock chambers mounted on the opposite ends of rotating arms centered on a central axle with a diameter of 35 metres.



Areas of Innovation

Hydraulic	O & M	Environment	Design / Construct	Misc
-----------	-------	-------------	--------------------	------

Lock Dimensions

Length	22	Lift:	33.5m
Width:	6	Depth	1.5



Braddock Dam (11-01)

Replacement of an existing lock and dam was completed by precasting and floating the new dam into place.



Segment 1 Alignment for Setdown

Areas of Innovation

Hydraulic	O & M	Environment	Design / Construct	Misc
-----------	-------	-------------	--------------------	------

Lock Dimensions

Length	182.8 m	Lift:	
Width:		Depth	

Charleroi (11-02)

Replacement and expansion of existing 17 m x 220 m and 17 m x 110 m locks with two new lock chambers, each 26 m x 220m done while maintaining traffic through the locks. Two innovative features highlighted:

Jump-form construction.

Local cofferboxes. Internally braced local cofferboxes will be used to construct many of the lock wall monoliths. The cofferboxes will be used to dewater local areas for conventional construction of these lock monoliths.

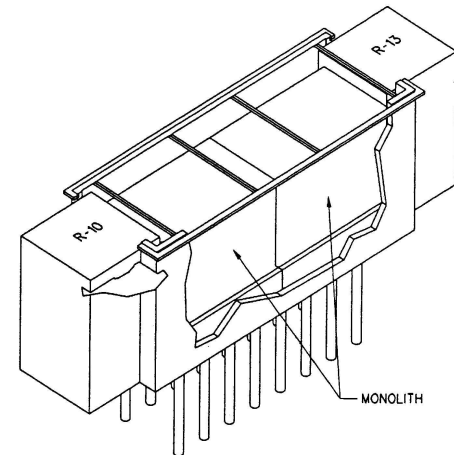
The cofferboxes will be composed of HZ kin piles, AZ sheet piling, internal bracing and a tremie concrete seal.

Areas of Innovation

Hydraulic	O & M	Environment	Design / Construct	Misc
-----------	-------	-------------	--------------------	------

Lock Dimensions

Length	220 m	Lift:	6 m
Width:	26 m	Dep	



Chickamauga (11-03)

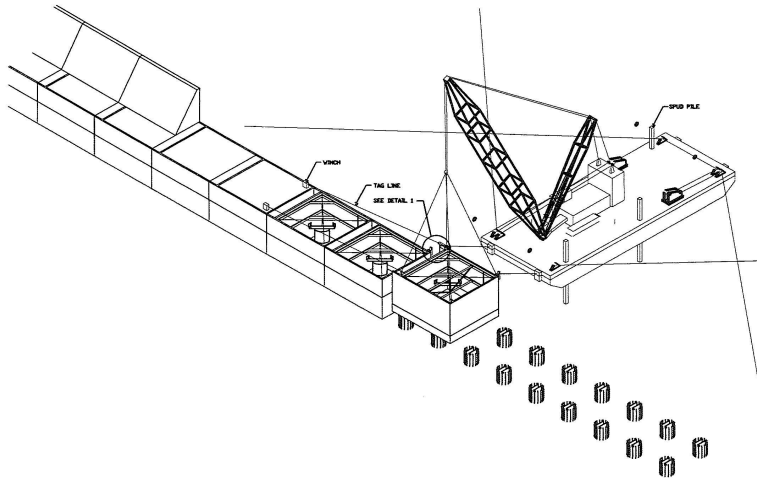
Lock renovation and expansion using lift-in construction techniques to work with difficult geological conditions and to maintain operation during construction.

Areas of Innovation

Hydraulic	O & M	Environment	Design / Construction	Misc
-----------	-------	-------------	-----------------------	------

Lock Dimensions

Length	183 m	Lift:	
Width:	34 m	Depth	



Greenup (11-04)

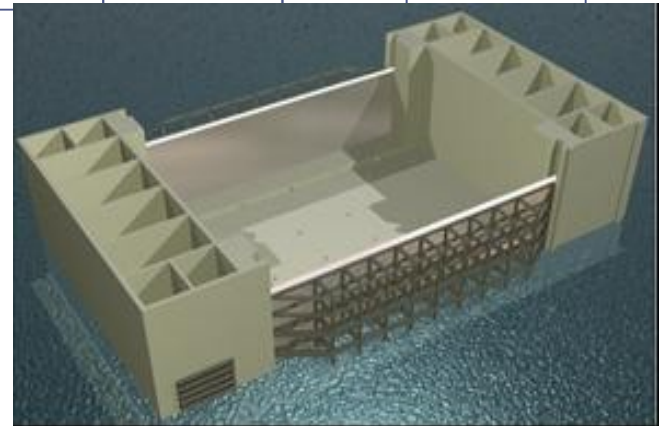
The Greenup plan of improvement includes a 183 m (600 ft) extension of the existing 183 m (600 ft) auxiliary lock to provide an overall length of 366 m (1200 ft), extension of the lock approach walls, filling and emptying system improvements, installation of a miter gate quick change out system for faster repairs to the lock miter gates and environmental mitigation. Extension of the auxiliary lock will be accomplished by lengthening the lock chamber with float-in concrete sections. This technique will utilize a dry dock at R.C. Byrd Locks and Dam to construct a concrete shell base raft. After the base raft is complete, the raft will be floated to a fit-out area at Greenup Locks and Dam where the walls are constructed on the base raft. The structure is then transported, positioned, and ballasted so that it will sink to its final position.

Areas of Innovation

Hydraulic	O & M	Environment	Design / Construct	Misc
-----------	-------	-------------	--------------------	------

Lock Dimensions

Length	366 m	Lift:	
Width:	33.5 m	Depth	



J.T. Meyers (11-07)

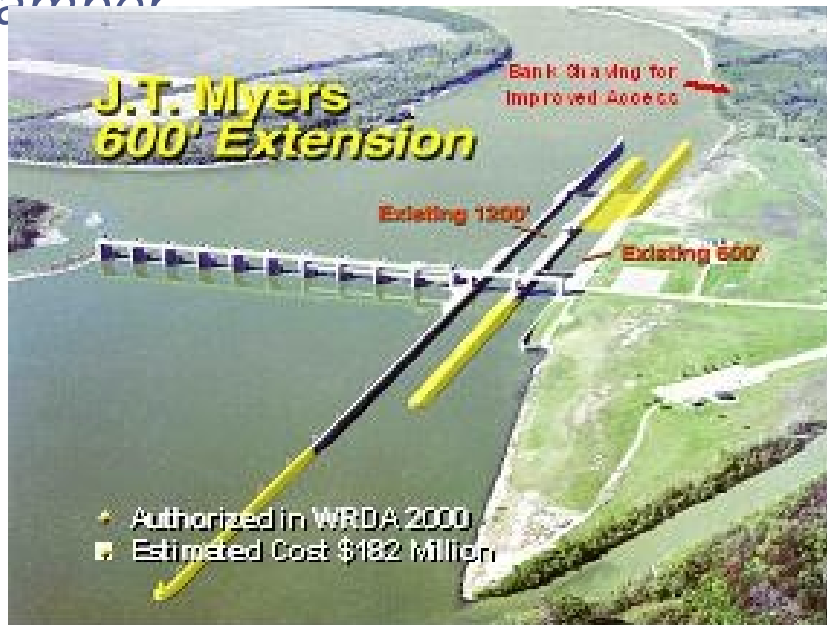
This project extends an existing lock from 34 m to 366 m **using float-in construction for the approach walls** and supplemental thru sill filling system for newly extended chamber

Areas of Innovation

Hydraulic	O & M	Environment	Design / Construct	Misc
-----------	-------	-------------	--------------------	------

Lock Dimensions

Length	366 m	Lift:	
Width:	34 m	Depth	



Inglis (11-05)

This innovation resulted in construction of a smaller lock inside a larger lock to save operating and maintenance costs, save fresh water, and improve manatee protection.



Areas of Innovation

Hydraulic	O & M	Environment	Design / Construct	Misc
-----------	-------	-------------	--------------------	------

Lock Dimensions

Length	50 m	Lift:	
Width:	12.2 m	Depth	

Kentucky Lock (11-08)

This project adds a new 366.0 m chamber adjacent to an existing 183.0 m chamber.

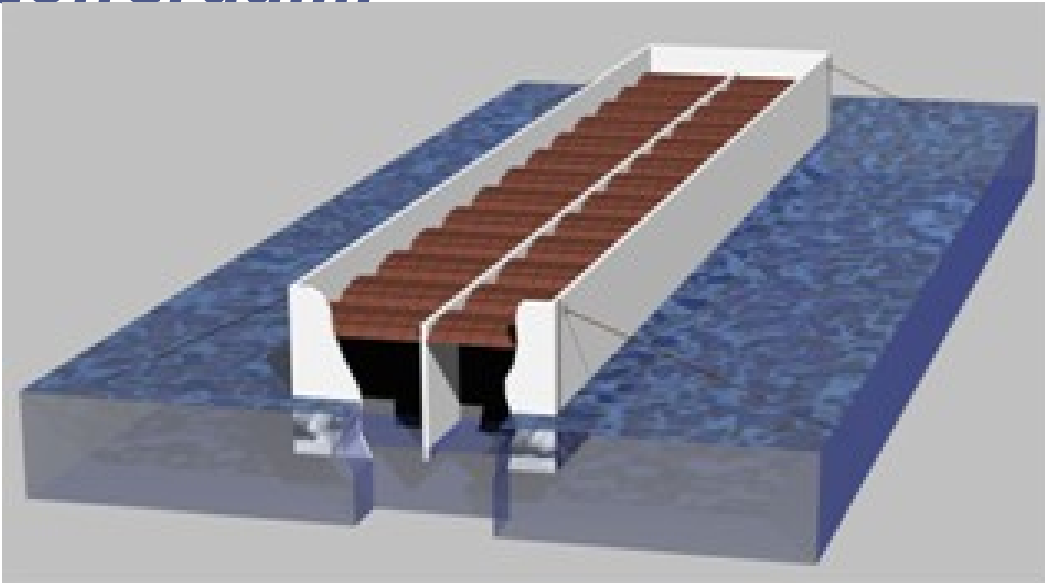
Construction utilizes and innovative float-in cofferdam.

Areas of Innovation

Hydraulic	O & M	Environment	Design / Construct	Misc
-----------	-------	-------------	--------------------	------

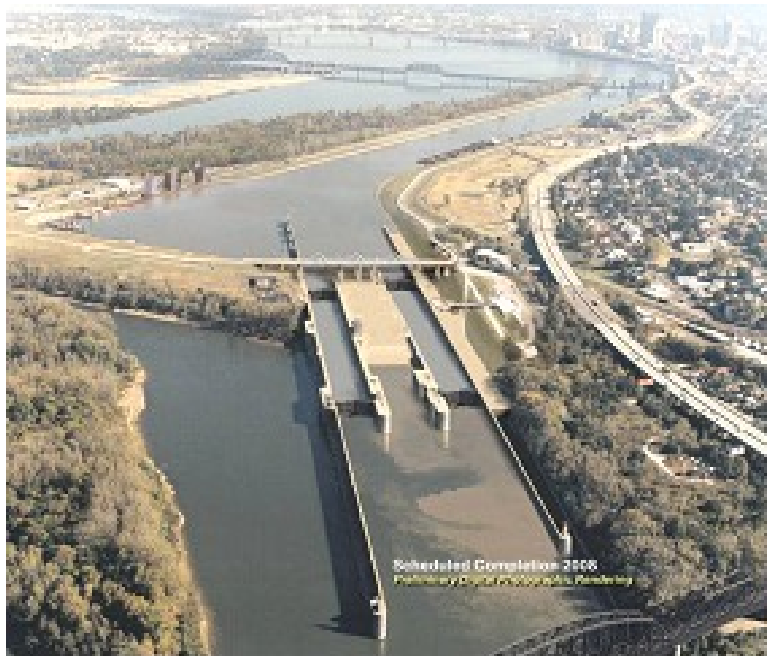
Lock Dimensions

Length	366 m	Lift:	
Width:	34 m	Depth	



McAlpine Lock (11-10)

*This lock expansion and renovation utilizes **roller compacted concrete (RCC)** for the new lock walls.*



Areas of Innovation

Hydraulic	O & M	Environment	Design / Construct	Misc
-----------	-------	-------------	--------------------	------

Olmsted Lock and Dam (11-11)

Expensive and deep foundations, high seismic design loads, large water level fluctuations and heavy bed loads provided an impetus to develop a floating solution for the Olmsted Approach walls.

A floating structure that is only anchored at each end instead of continuously or intermediately along the length as is typical for fixed structures would meet this goal.

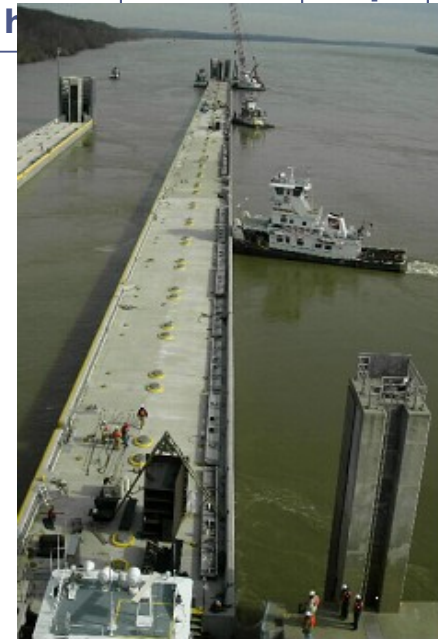
A structure that floats would also never be submerged; thus eliminating the requirement to wash mud from the structure.

Areas of Innovation

Hydraulic	O & M	Environment	Design / Construct	Misc
-----------	-------	-------------	--------------------	------

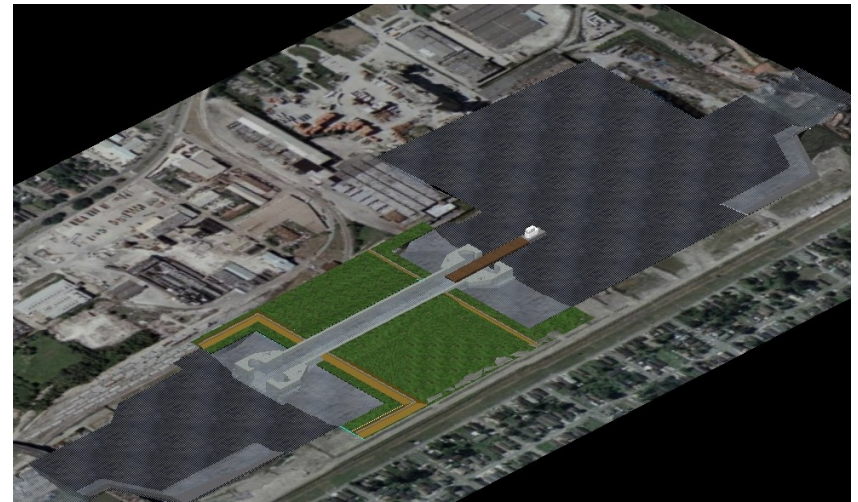
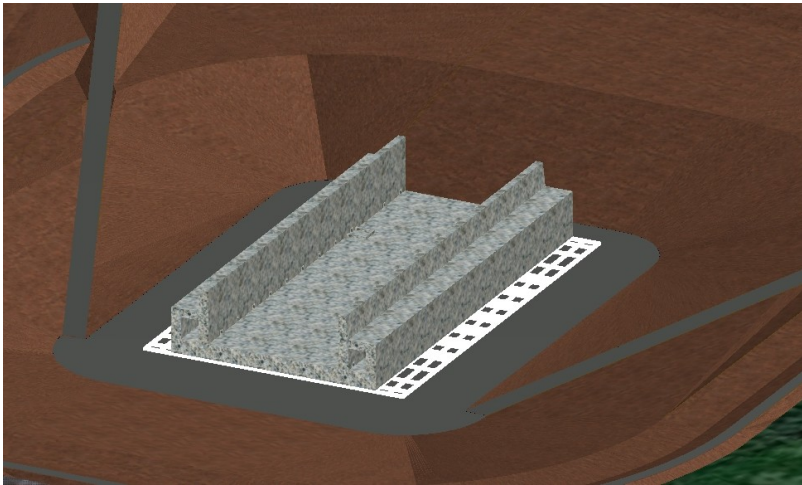
Lock Dimensions

Length	366 m	Lift:	
Width	33.5 m	Depth	



IHNC Float-In Lock

*This project replaces an existing lock **using float-in construction**. The 5 modules are built in a off site dry graving yard and then floated in place.*



Build Module in dry Graving Site Lock Modules Floated in place

Troy Lock (11-12)

This older lock with deteriorating lock walls was retrofit with precast panels.

Resulting in a savings in cost, construction, and a potentially higher quality finish



Areas of Innovation

Hydraulic	O & M	Environment	Design / Construct	Misc
-----------	-------	-------------	--------------------	------

Lock Dimensions

Length	150 m	Lift:	
Width:	13.5 m	Depth	4.9 m



Winfield Lock Approach Wall
Beam Placement



- Donut Fender Approach Wall, Emden Lock, Germany



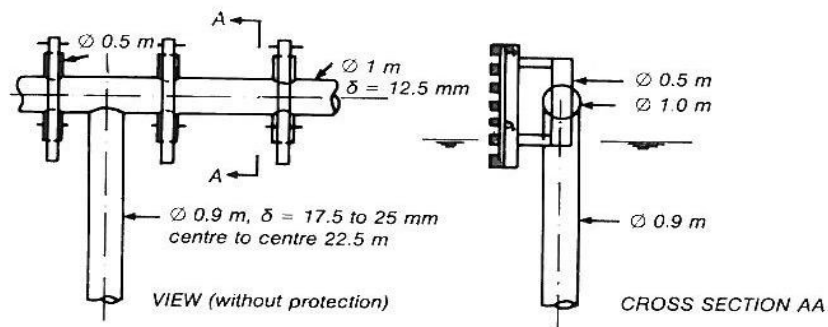


FIG. 2.1 FIXED FENDER STRUCTURE
(Middensluis Terneuzen)

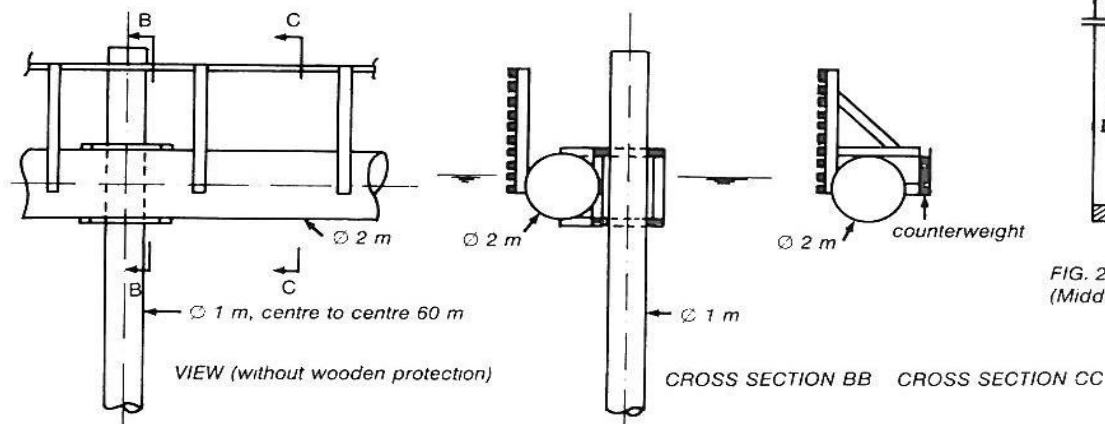


FIG. 2.2 FLOATING FENDER STRUCTURE WITH FIXED PILES
(Krammer locks)

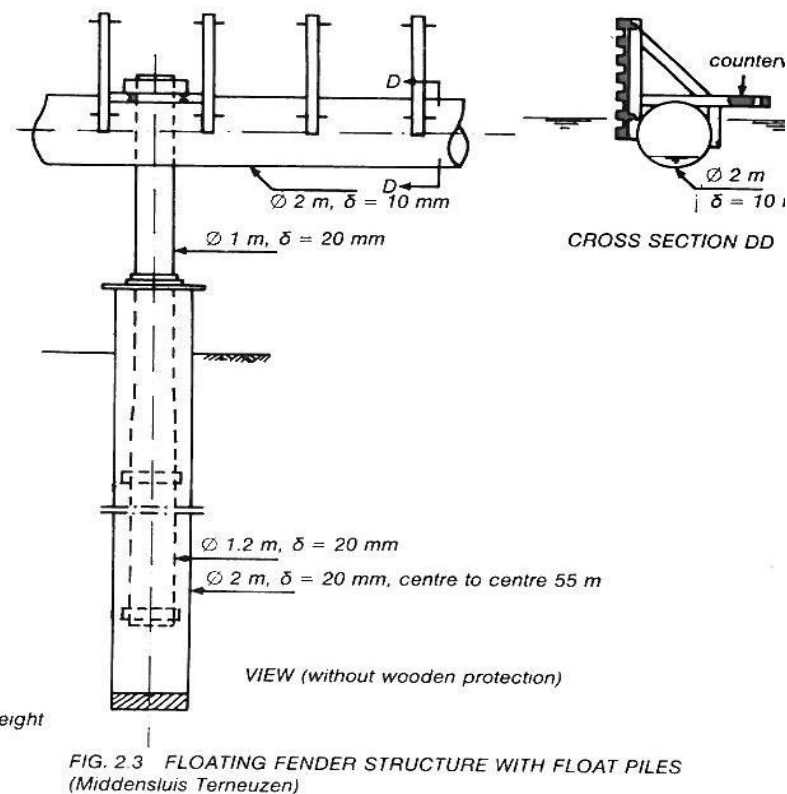


FIG. 2.3 FLOATING FENDER STRUCTURE WITH FLOAT PILES
(Middensluis Terneuzen)



Damaged Timber Wall

Conclusions

INCOM WG 29 expects to finalize this work before the end of 2008, so the report will be available in 2009.

→Feedback and comments on this paper are welcome and will be considered for the final report

Thank you



Questions

Mengli Navigation Lock (3-05)

The lock is a part of the hydropower plant. Purpose of the project power generation, improving navigation and irrigation conditions. Innovations are provided in the filling and emptying system.

Areas of Innovation

Hydraulic	O & M	Environment	Design / Construct	Misc
-----------	-------	-------------	--------------------	------

Lock Dimensions

Length	140 m	Lift:	
Width:	14 m	Depth	2.5 m

